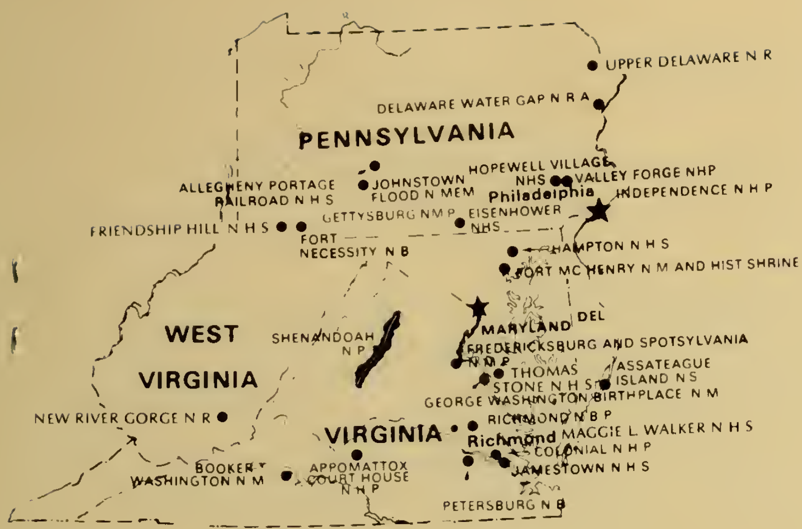
FRHI



MID-ATLANTIC REGION

RESEARCH/RESOURCES MANAGEMENT REPORT

FRIENDSHIP HILL NHS
TREATMENT OF ACID MINE DRAINAGE
BY A PILOT-SCALE WETLAND

U.S. DEPARTMENT OF THE INTERIOR

NATIONAL PARK SERVICE

MID-ATLANTIC REGIONAL OFFICE
143 SOUTH THIRD STREET
PHILADELPHIA, PENNSYLVANIA 19106

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PROJECT REPORT
IA 4000-5-0010
(September 1986 - October 1987)

FRIENDSHIP HILL NHS
TREATMENT OF ACID MINE DRAINAGE
BY A PILOT-SCALE WETLAND

U.S. Department of Interior
Bureau of Mines
Pittsburgh Research Center

July 1988

FRIENDSHIP HILL PILOT-SCALE WETLAND

INTRODUCTION

The wetland construction design selected for Friendship Hill (FRHI) was intended to minimize construction costs yet result in sufficient vegetative growth to treat Ice Pond Run acid mine drainage (AMD). Organic substrate material in the form of readily available hay bales was used for the two *Sphagnum* plots. Fertilizer pellets were intended to support the four *Typha* plots in the remainder of the wetland system. *Sphagnum* was chosen for the wetland because at the time it was the plant type considered most effective for treatment of heavily contaminated AMD. Recent data and field observations at Friendship Hill and other wetland sites have shown that *Sphagnum* has a limited treatment capacity for moderate to strong AMD. The limited duration performance of the *Sphagnum* sections at Friendship Hill bears this out. *Typha* was chosen for the same reasons as *Sphagnum* and is still considered a viable plant type for the treatment of various strengths of AMD. Several constructed *Typha* wetlands currently exist that are successfully treating AMD similar to that of Ice Pond Run, at least in the short-term. However, a significant difference between these sites and the Pilot-Scale Wetland are that the *Typha* was planted in a rich organic substrate which had alkaline materials incorporated in it. The role of alkaline substrates in *Typha* wetlands is not well understood yet. In fact, the several processes that in concert constitute the wetland AMD treatment system only recently have begun to be researched in detail.

The Pilot-Scale Wetland at Friendship Hill did indeed remove iron and sulfate for about a five month period before it ceased to perform effectively. During that time, the *Sphagnum* sections generally removed the majority of the sulfate treated by the wetland and the *Typha* sections removed the majority of the iron. We believe that in addition to the stressful conditions under which the *Sphagnum* was established, the AMD treatment capacity of the *Sphagnum* was consumed faster than the *Sphagnum* was able to regenerate capacity through growth. The *Typha* were not able to become firmly established due to the strength of the AMD and the absence of a suitable rooting substrate. The Pilot-Scale Wetland performance, as well as remedies and a revised state-of-the-art wetland design, are detailed in the following report.

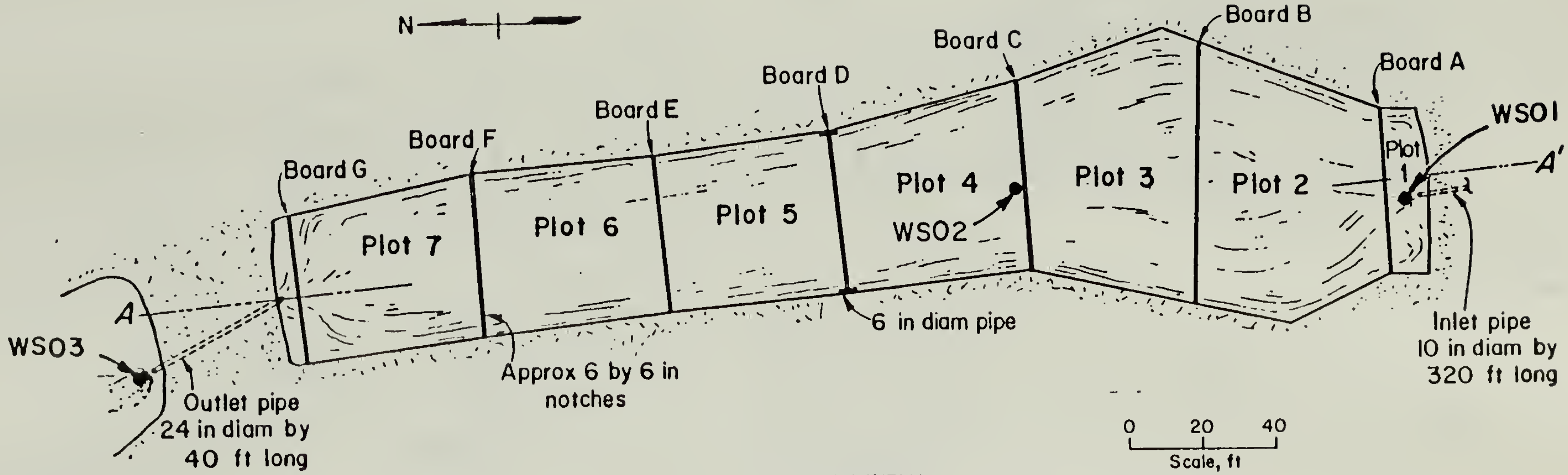
PILOT-SCALE WETLAND PERFORMANCE

CONSTRUCTION

Construction diagrams of the Pilot-Scale Wetland are shown in Figures 1-3. Figure 1 is a plan view, figure 2 is the plan view with the planting scheme overlain on it, and figure 3 is a longitudinal cross-section of the Pilot-Scale Wetland. The wetland was constructed in mid-summer of 1986 by Bureau of Mines and NPS-FRHI personnel. An excavation was made, 316 ft long by 40-70 ft wide, encompassing a total of about 15,000 square feet. The design flow through the wetland was 20 gal/min, although the area of the wetland could, based on wetland construction practice, treat about 60 gal/min. The initial depth of the wetland was set between 0.7 and 1.0 ft. The base of the excavation, on natural clay, provides an average 1% grade from inflow to outflow. Seven sets of boards were placed across the width of the wetland to

FIGURE 1

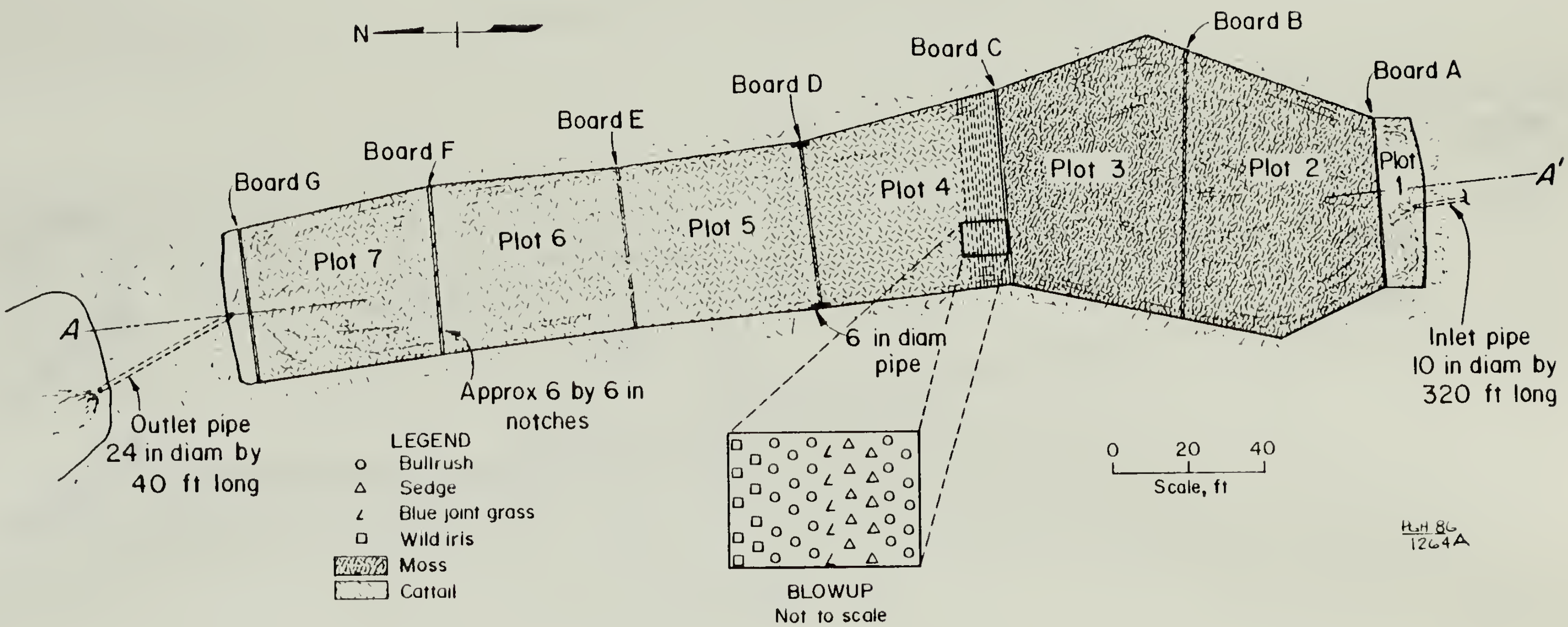
FRIENDSHIP HILL CONSTRUCTED WETLAND



PLAN VIEW

FIGURE 2

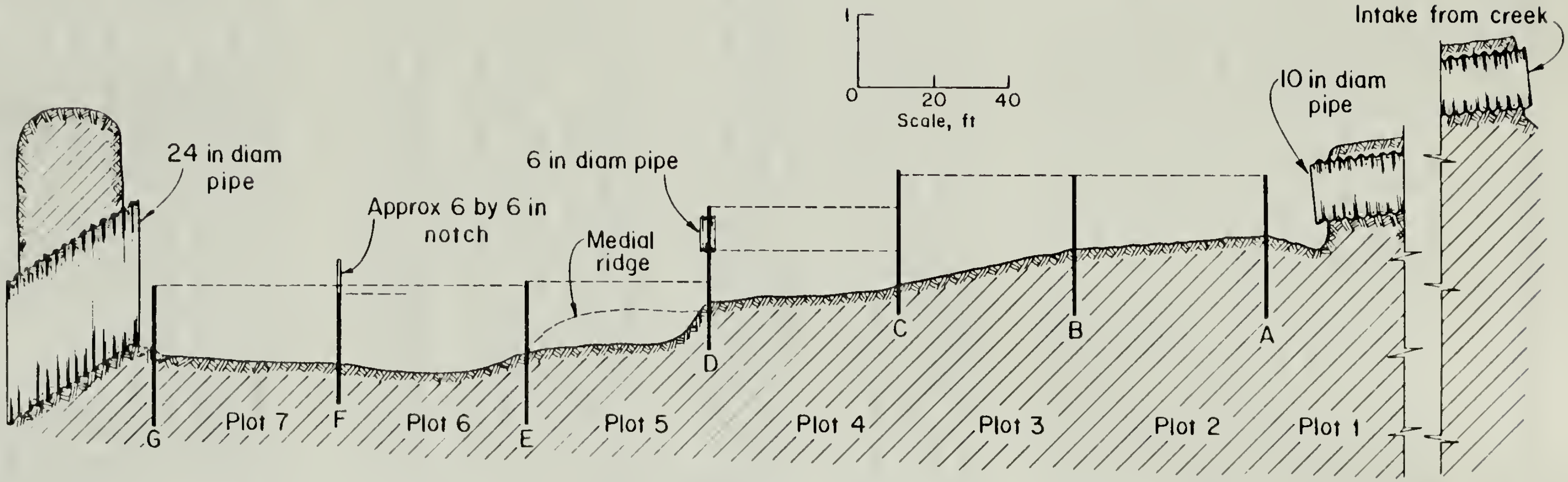
FRIENDSHIP HILL CONSTRUCTED WETLAND



PLAN VIEW

FIGURE 3

FRIENDSHIP HILL CONSTRUCTED WETLAND



SECTION A–A′

separate it into seven plots and regulate water depth. Water flows between plots by running over the boards.

Above the wetland a dam was built across Ice Pond Run to provide a pool from which water could be diverted into the wetland. Flow runs through an adjustable sluice gate, into 320 ft of buried 10-inch plastic pipe, and empties in plot 1. A 24-inch pipe was placed down-gradient from the last set of boards, to channel the outflow from the system for sampling and flow measurement. The dam performed well until Spring 1987. During severe rainstorms in early April, 1987, serious erosion occurred around and under the dam. Flow into the wetland was not lost, but concerns about the effects of further erosion prompted repair efforts. In August, 1987 the pool was deepened and the dam increased in size and extent. At the same time a concrete gauging flume was built below the wetland. Outflow water (from plot 7) now flows through this flume and it will soon be equipped with an automatic flow monitoring device. Thus far, the new system has satisfactorily weathered several high flow events.

Locally collected Typha were planted in late August, 1986 in plots 1 and 4 through 7. Plants were collected from a freshwater seepage area and from a stand of volunteer Typha growing in a local coal yard. Individual plants consisted of roots and emergent leaves, and were planted on 3 ft centers directly in the wetland's clay base.

A small section of plot 3 was planted in September, 1986 with a variety of emergent aquatic plants obtained from a nursery in Wisconsin. These included soft- and hardstem bullrushes, three species of Carex, wild iris, and bluestem jointgrass (figure 2).

On November 13, 1986 plots 2 and 3 were planted with 40,000 lb. of live Sphagnum purchased from a Wisconsin peat moss quarry. The moss was purported to be dominantly S. recurvum. Plot 2 and half of plot 3 had been previously filled with bales of hay and the moss was set directly on top of the inundated bales. In areas with no hay bales the moss itself was used to build up the substrate for its optimum growth above the water surface.

The only amendments made to the wetland's vegetation were slow-release fertilizer tablets buried in the clay around each cattail in April 1987.

OPERATION AND MAINTENANCE

The Pilot-Scale Wetland became operational in September 1986 when water was diverted into the system. Maintenance activity consisted mainly of regulating flow and water depth. Water depths in the cattail sections initially were too high for good cattail growth and treatment performance. Consequently, 6-inch pipes were placed at each end of board D (see Figure 1) during October 1986. The water depth range was reduced to 0.3 to 0.5 ft. A weir was installed in the outflow pipe during December 1986 to allow periodic flow measurement prior to installation of the outflow flume and water level recorder. Notches were made in the plot-separation boards except board A to lower water levels in the wetland as the pipes had caused channelized flow in the plots. A weir was installed in the inflow pipe in August 1987, after we found that the sluice

gate design did not permit the use of standard equations for flow calculation.

PERFORMANCE

Water Flow

Flow was determined weekly after December 1986 by reading a pipe weir at the wetland outflow and weekly after July 1987 by reading a pipe weir at the inflow. During late August and September 1987 inflow and outflow rates were approximately equal. Thus, we consider it reasonable to assume that inflow rates were approximately equal to measured outflows for earlier months.

Flow through the wetland was quite variable, ranging from 600 to over 200,000 gallons per day (gpd) or 0.4 to over 139 gal/min. The average flow over the October 1986 to September 1987 period was 36,000 gpd (25 gal/min). The wetland was designed to treat 30,000 gpd of flow. Extremely high flows resulted from Ice Pond Run overtopping the sluice gate following rain storms before reconstruction of the Ice Pond Run diversion and increasing the height of the sluice gate.

Water Chemistry

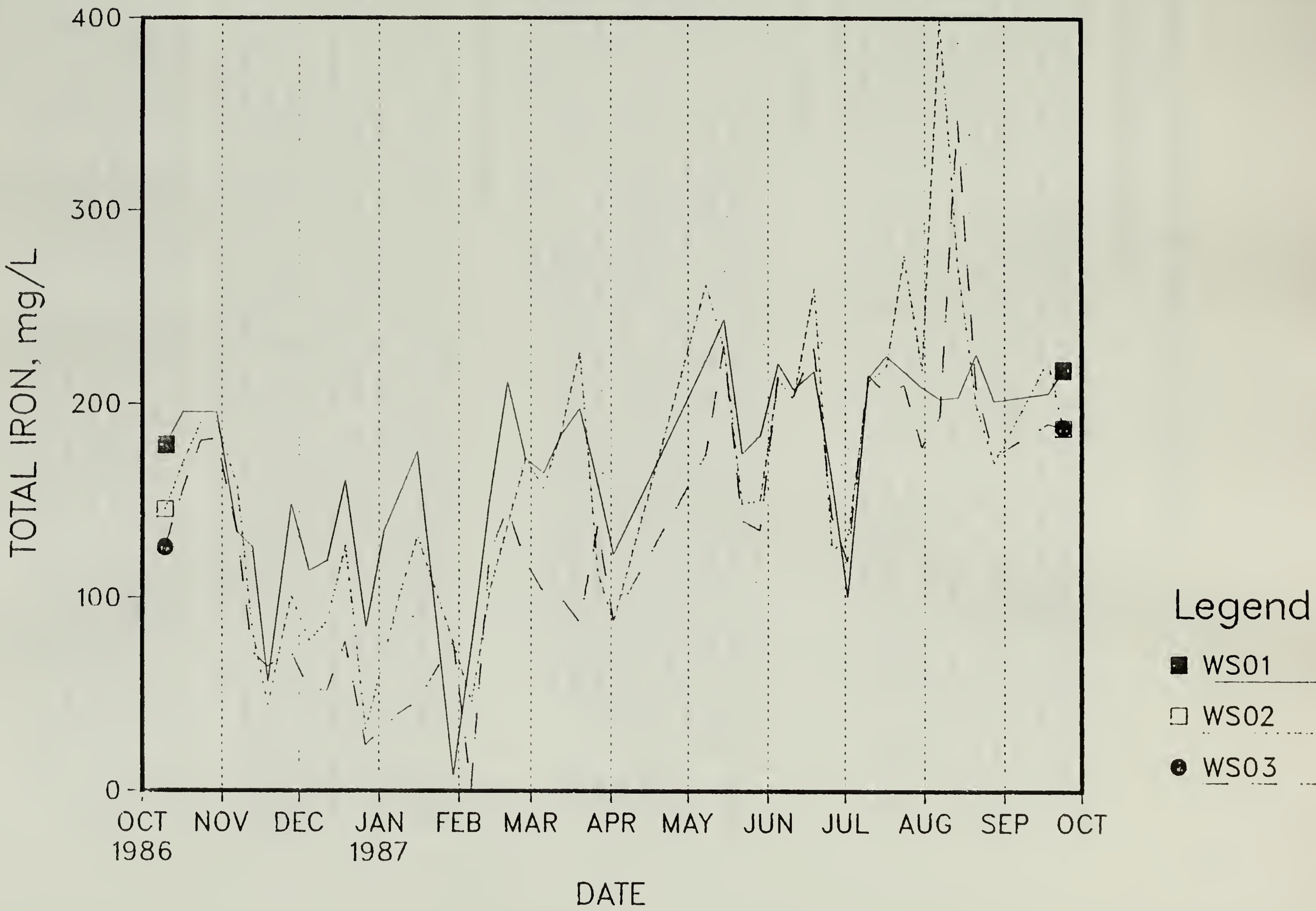
Water samples were collected weekly at the inflow pipe (WS01), at board C separating the *Sphagnum* and *Typha* plots (WS02), and the outflow (WS03) (Appendix A). Water pH, which averaged 2.8 at the inflow, was only increased by 0.1-0.3 units by the wetland. Significant differences between the inflow and outflow chemical data were observed for iron, sulfate, aluminum and manganese. Because the largest reductions were in iron concentrations, and the patterns of removal generally paralleled those of manganese and aluminum, only iron removal will be discussed in detail. Graphs of the data are presented as figures 4-6 and Appendix B.

Iron Removal

Figure 4 is a graphical presentation of the iron data. Five sets of water samples were collected before the *Sphagnum* was planted. During this period, plots 2 and 3 contained hay bales, and plots 4-7 had been planted with *Typha*. Minor, but significant changes in water chemistry were apparent on these five weeks. Outflow Fe concentrations averaged 20 mg/L less than inflow. Most of this reduction occurred in the *Typha* plots.

During the four months following the planting of *Sphagnum*, iron concentrations at the outflow averaged 79 mg/L less than the inflow. This was a 52% reduction in total iron. The *Sphagnum* plots removed, on average, 32 mg/L. In April and May, 1987 total removal of iron decreased to an average 31 mg/L (17% of inflow). This was partly due to very high flow rates in early April, but even during moderate flow periods, removal was less than earlier in the year. Of the 31 mg/L removed, 19 mg/L occurred in the *Sphagnum* plots.

Since June 5, 1987 concentrations of iron and all other metals have not been reduced by the wetland. On one day, August 14, iron concentrations in the outflow were 130 mg/L higher than the inflow indicating remobilization of iron



400
300
200
100
0
TOTAL IRON, mg/L
OCT
1986
NOV
DEC
JAN
1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03

previously removed by and deposited in the wetland.

Oxidation/Reduction of Iron

Changes in the oxidation state of dissolved iron occurred through the wetland. As seen in figure 5, 97% of the iron in the inflow was in the ferric form (oxidized, Fe^{3+}), while the average of the outflow was 70%. Virtually all of the iron reduction occurred in the *Sphagnum* plots presumably due to the anaerobic decomposition of the submerged hay bales. When flow rates were low, much of the reduced iron was re-oxidized in plots 4-7. When flows were high, less oxidation of iron was observed in these plots. Removal of total iron in the *Typha* plots was strongly correlated with the amount of reduced iron entering the plots (correlation coefficient r=0.86). This suggests that the primary mode of iron removal in these sparsely vegetated plots was oxidation and sedimentation of reduced iron, probably aided by bacteria such as *Thiobacillus*.

Sulfate Removal

Figure 6 shows sulfate removal for the wetland system. During the short period of effective wetland performance, more than half of the sulfate removal occurred in the *Sphagnum* plots. The most likely mechanism was sulfate reduction. The environmental conditions produced by slow flow of sulfate-rich water through hay bales are ideal for dissimilatory sulfate reduction by bacteria such as *Desulfovibrio*. During this process, sulfate is converted to hydrogen sulfide which either reacts with dissolved metals and precipitates, or bubbles out (of the wetland). We occasionally observed H_2S odors in the *Sphagnum* sections, and submerged hay bales were covered with black residues that a microbiologist identified as iron sulfide compounds (visual observation, Dr. Henry Spratt).

Vegetation Performance

During the winter and spring of 86/87, the *Sphagnum* plots were green. In May the green color began to fade and by mid-July the *Sphagnum* was brown. During the decline, live plants were often covered with white crystals that, upon analysis, proved to be gypsum. In late July we collected samples of the brown moss and provided them with fresh water in a laboratory. After a month, no development of green color had occurred, indicating that the moss was indeed dead. Samples of dead moss, which were extracted with a sodium pyrophosphate solution, were found to contain 18,000 ppm organically bound iron, in contrast to an original content of 1500 ppm. This value is comparable to ones reported by Wieder and Lang for peat from a natural wetland that had received low level AMD for about 20 years, and may represent a metal saturation level.

Over 90% of the *Typha* plants sent up shoots in spring of 1987. However, they also began to decline in late spring, and by August only 20% of the plants remained alive. We had expected that the plants would completely fill the plots by mid-summer as had occurred at many other sites. However, very few of the plants sent up new shoots, and little filling in of the area around living plants occurred. Survival of *Typha* was highest in plot 4 and lowest in plots 6 and 7. Mortality may have been related to water depth, which was greater

FIGURE 5

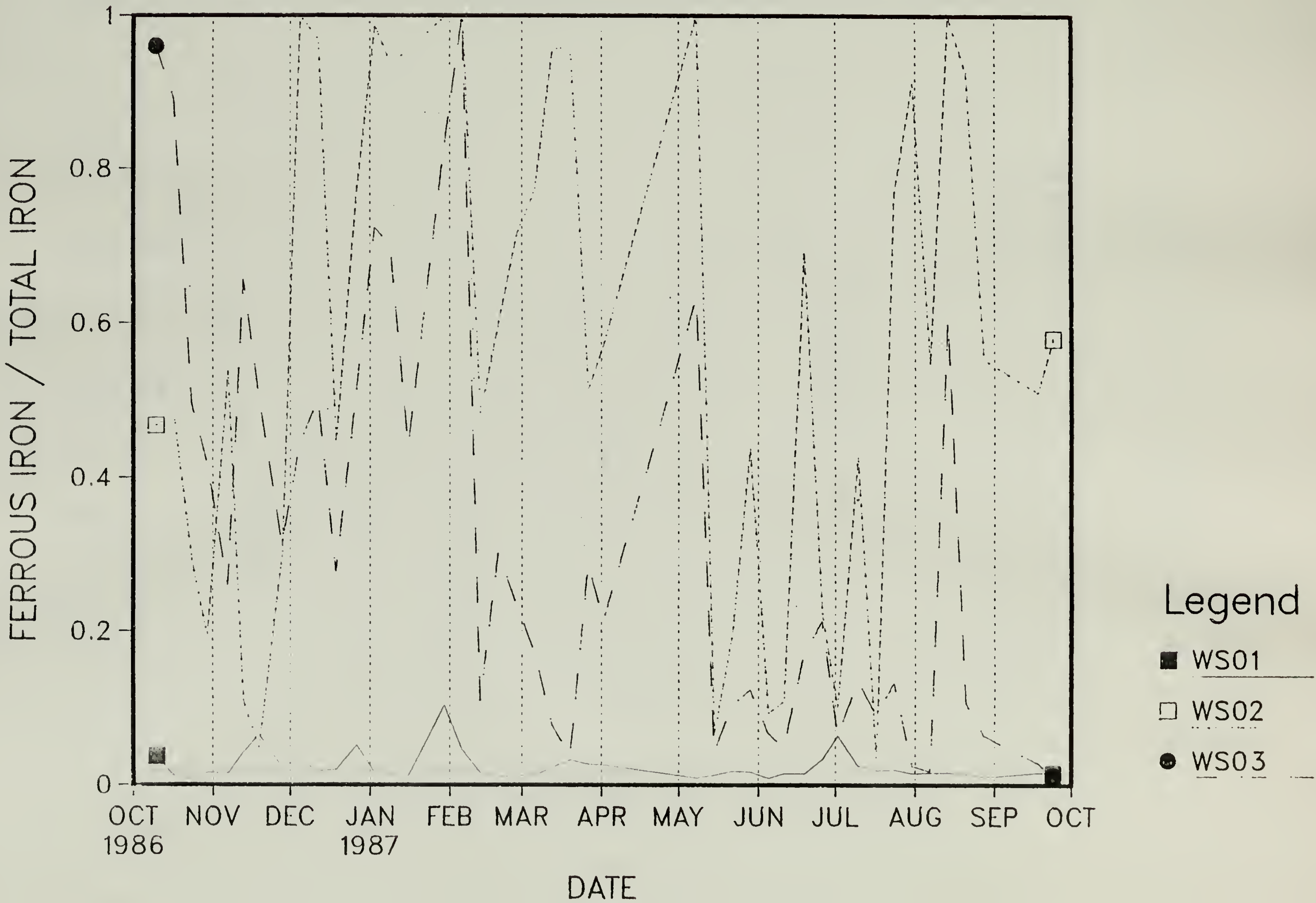
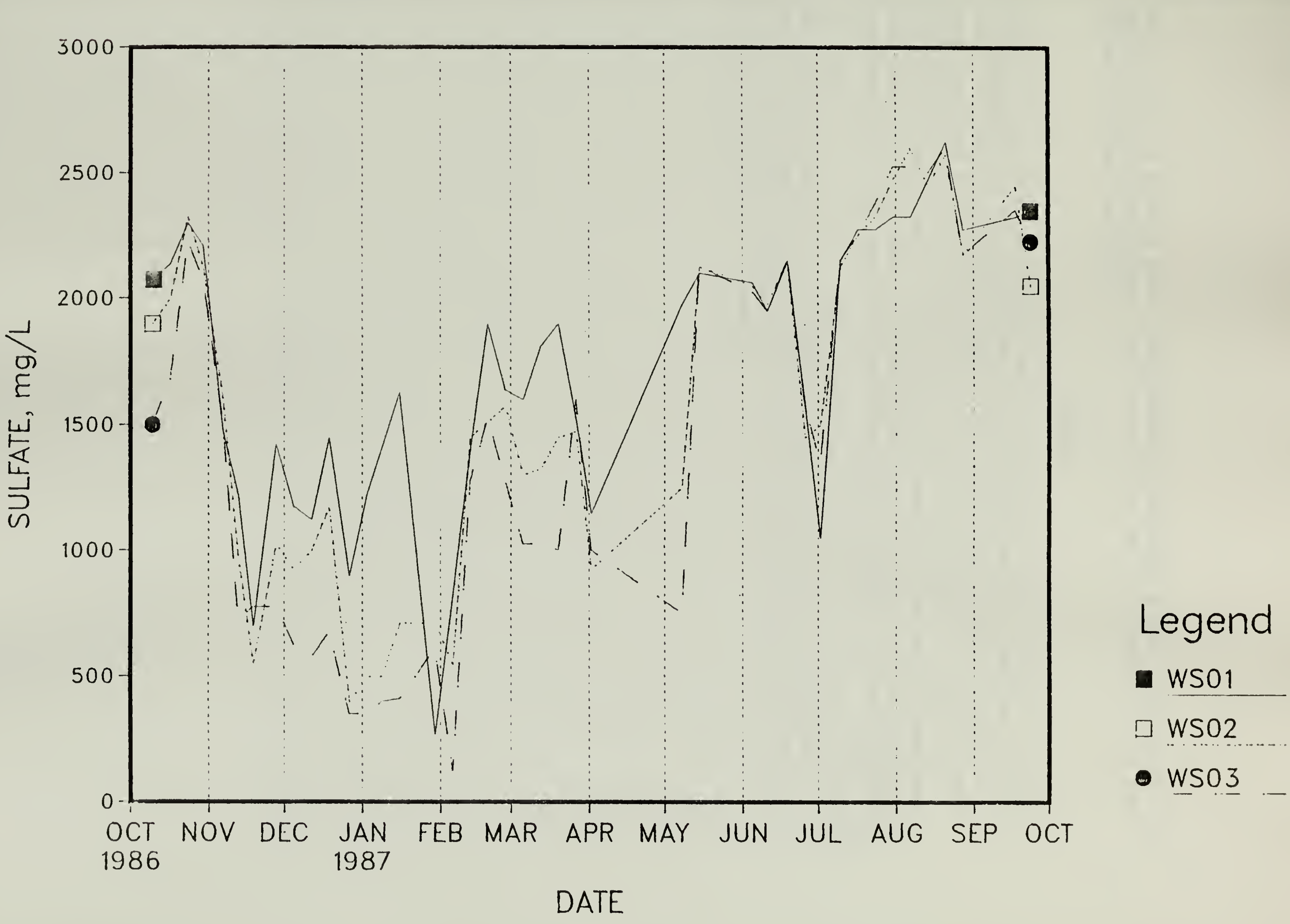

FERROUS IRON / TOTAL IRON
1
0.8
0.6
0.4
0.2
0
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03

FIGURE 6


SULFATE, mg/L
3000
2500
2000
1500
1000
500
0
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03

than 0.7 ft. in plots 6 and 7, and generally less than 0.5 ft. in plot 4. The apparent lack of a sufficient rooting substrate and the strength of the AMD further stressed the Typha.

SUMMARY

Results of the pilot-scale experiment indicate that construction of a wetland with Sphagnum moss and Typha planted in an infertile, clay substrate will not result in a viable ecological community or provide satisfactory long term water treatment given the strength of AMD at Friendship Hill. The addition of Sphagnum moss to the wetland did cause significant removal of metals and sulfate for several months. Unfortunately, eventually the moss accumulated toxic levels of iron, died, and water improvement ceased. Planted Typha also experienced very high mortality and nowhere did it become as dense as desired.

Our attempt at a low cost, simple design wetland solution to treating Ice Pond Run AMD was successful only in the short term. Many physical problems occurred and plagued the experiment in 1986/87, such as flow control and measurement problems, washout of the dam, and depth problems in some plots. These were successfully corrected.

FIGURE 7

Figure 7.--Site 2 three - Typha cell wetland.

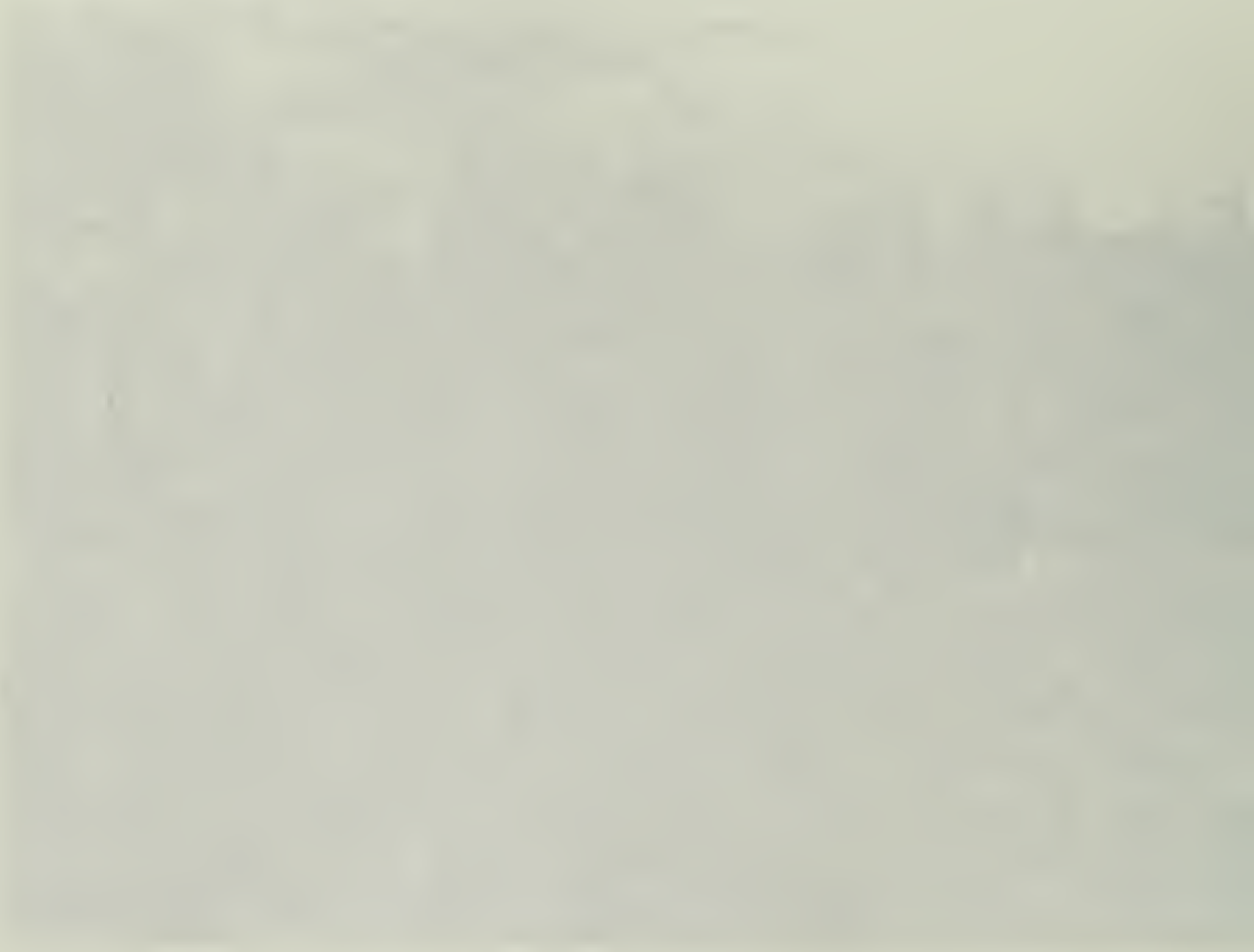


FIGURE 8

Figure 8.--White - rimmed alkaline zones in Site 2 wetland substrate.

FIGURE 9

Figure 9.--Close-up view of alkaline zone in Site 2 wetland substrate.

PROPOSED CHANGES FOR FRIENDSHIP HILL PILOT-SCALE WETLAND DESIGN

BACKGROUND

During the winter and early spring of 1987, concentrations of total iron (Fe) in the outflow averaged 79 mg/L less than the inflow. During this period the Sphagnum was green and 80-90% of the cattails were sprouting. Between mid-April and early August Fe concentrations were only reduced by 15 mg/L. Since August 14, Fe concentrations have not been reduced by the wetland. Concurrent with the decrease in Fe removal were visible changes in the vitality of the moss and cattails. By August the Sphagnum had developed a rust color and was 95% dead. During this same period, over 80% of the cattails died. There was negligible clonal expansion of those that survived.

These results show that long term water quality improvement cannot be achieved at Friendship Hill by simply creating a shallow water system and planting it with Sphagnum and Typha. Had this experiment worked, a very inexpensive, simple solution for the Friendship Hill water problem would have been feasible. In hindsight, it appears that the Ice Pond Run water is too acidic and metal-laden to expect such an easy solution. In this section of the report we outline plans for further research in the Pilot-Scale Wetland that would address questions of substrate and alkalinity additions which, while more costly than the initial design, are required to establish a viable wetland. While we propose to evaluate the results of our proposed research for a period of one year, it is desirable to continue to evaluate this research over a two to three year period. If the results of this research lead to a full scale wetland system at FRHI, we would like to maintain the Pilot-Scale Wetland for further research.

In separate research activities, we have observed constructed wetlands that to date are successfully treating acid mine drainage that is chemically similar to the Ice Pond Run (Friendship Hill) AMD.

	pH		Acidity		Total Fe		Manganese		Sulfate	
SITE	in	out	in	out	in	out	in	out	in	out
Site 1	2.8	6.2	318	<10	84	4	38.4	17.4	1300	640
Site 2	2.7	5.1	930	45	177	15	43.3	33.0	2225	1675
Ice Pond Run	2.7	2.7	1284	1230	218	188	11.7	10.8	2350	2225

Both of the functioning sites are dense Typha wetlands constructed with a limestone bed covered with 12-18 inches of mushroom compost. At Site 2, cattails are growing quite well and reproducing clonally at the inflow, where pH is 2.7. This indicates that cattails can grow in extremely acid water if they are provided a suitable rooting substrate. Figure 7 is a photograph of the Site 2. In the original Pilot-Scale test we attempted to grow Typha in a compacted clay substrate. By providing a fertile organic substrate, we expect that Typha establishment and growth should not be a problem in the future.

A very important feature of both the Site 1 and 2 is the presence of alkaline

materials that raise the pH and appear to stimulate biological activity, especially at the water-substrate interface. At Site 1 the alkalinity is also provided by surface applications of lime. At Site 2 higher pH values are found in stagnant areas where black sediment and white plumes are observed. Figures 8 and 9 are photographs of these areas. The result of increased pH is the same at both sites: black sulfur-rich suspended sediments form and CO_2 and H_2S bubble to the surface. These conditions are indicative of high microbial reducing activity and are suspected to result in the formation of metal sulfides, hydrogen sulfide gas, and the generation of further alkalinity.

PROPOSAL

We propose to modify the Pilot-Scale Wetland design so that we can test the effectiveness of a Typha/mushroom compost system with varying methods of alkalinity generation. The results should allow us to advise the National Park Service about:

1) the feasibility of establishing a Typha wetland system in Ice Pond Run;

2) whether alkaline materials are necessary to establish the wetland and cause improvements in water quality;

3) whether alkalinity should be supplied as a one-time substrate addition, or as a periodic (semiannual or annual) surface application.

The ultimate goal of our proposed wetland system is to develop a system that requires only annual maintenance (fertilizer and/or alkaline additions) and will yield a discharge of pH 6-8, iron concentrations <3 mg/L, and manganese concentrations <2 mg/L. In light of the severity of Ice Pond Run AMD and the general lack of data on long-term wetland performance, our pragmatic goals are to establish a viable vegetative wetland community, lower the iron concentrations to about 50 to 75 mg/L, and raise pH to about 4.

The Typha plots (numbers 4, 5, 6, and 7) will be reconfigured into two sections (or cells), separated from the Sphagnum plots and from each other by earthen berms. Three lanes of water flow will be created in each cell using corrugated fiberglass paneling. Each lane will be filled with 18 inches of mushroom compost. Each lane will be planted with cattails that will be collected locally. Planting will be at a higher density than was used previously. Lane A, the alkalinity control lane, will have at its base 6 inches of con-calcareous river gravel. Lanes B and C will have at their bases 6 inches of limestone gravel. Lane C will also receive periodic surface additions of alkaline materials. This topical addition of neutralizing capacitiy is a common practice in wetlands that treat extremely acidic water, but its actual effect has never been determined.

Water will flow between cells (but within lanes) by way of PVC plumbing installed in the berm separating the cells. The second set of cells will also contain an "underflow" system which will allow inflow of water in the gravel at the wetland base. In each lane, two 55 foot perforated PVC pipes will be buried in the gravel. These pipes will be connected to the outflow pipe from the preceding cell. By turning a valve, we will be able to direct water

either into the underflow system or have it enter at the substrate surface.

This design will allow comparisons of metal, acidity, and sulfate removal in a _Typha_/mushroom compost system that is subjected to additions of alkalinity beneath the substrate, at the surface, and a control (no alkalinity). This aspect of the design has important implications for the eventual design of a full scale wetland because it will determine how to best neutralize the extremely high acidity contained by Ice Run water. We will also experimment with a novel underflow system. This flow system should cause movement of water through anaerobic organic materials and thus stimulate reducing reactions. Preliminary work at the Bureau suggests that reducing processes are the only feasible manner to biologically remove iron and acidity from AMD.

We are also trying to develop a source of freshwater that could be used to dilute water in the pilot wetland for 1-2 months after planting. Our vegetation plot experiments during 1986 found large differences in density and growth between _Typha_ planted in freshwater and not exposed to AMD for one month versus _Typha_ planted directly in AMD.

The Plots

PLOT 1 — Currently no vegetation or substrate;
No changes at this time;

PLOT 2 — Currently haybale substrate with dead _Sphagnum_ on top;
No changes at this time.

PLOT 3 — Currently a mixture of dead _Sphagnum_ on hay bales and dead _Sphagnum_ on peat; no changes at this time;

PLOTS 4-7 — Currently planted with _Typha_, no substrate.

Reconfigure, with bulldozer, into two cells. Each cell will be 70 feet long and 3 feet deep. Cells will be separated from each other, from the _Sphagnum_ plots, and from the outflow pipes by earthen berms, about 20 feet wide at base and 10 feet wide at top.

In each cell construct three separate lanes of water flow (A,B,C) using two corrugated fiberglass "fences." Water into the first cell in each lane will come from a common source in the _Sphagnum_ plot. Water will flow between cells by way of PVC plumbing. The second cell of each lane will also contain a PVC "underflow" system which will allow input of water, from the first cell in each lane, directly into the river rock or limestone gravel at the wetland base. Water will then flow up through the substrate, instead of on top of it, as is the case in all other constructed wetlands. Control of water flow into these cells (surface of underdrain) will be via PVC valves in the berm separating the first and second cells.

Fill lanes with the following substrate:

lane A: both cells with 6 inches of non-calcareous river gravel and 18 inches of mushroom compost

lane B: both cells with 6 inches of limestone gravel and 18 inches of mushroom compost

lane C: both cells with 6 inches of limestone gravel and 18 inches of mushroom compost

Plant all cells with _Typha_ at a density of one plant per square foot.

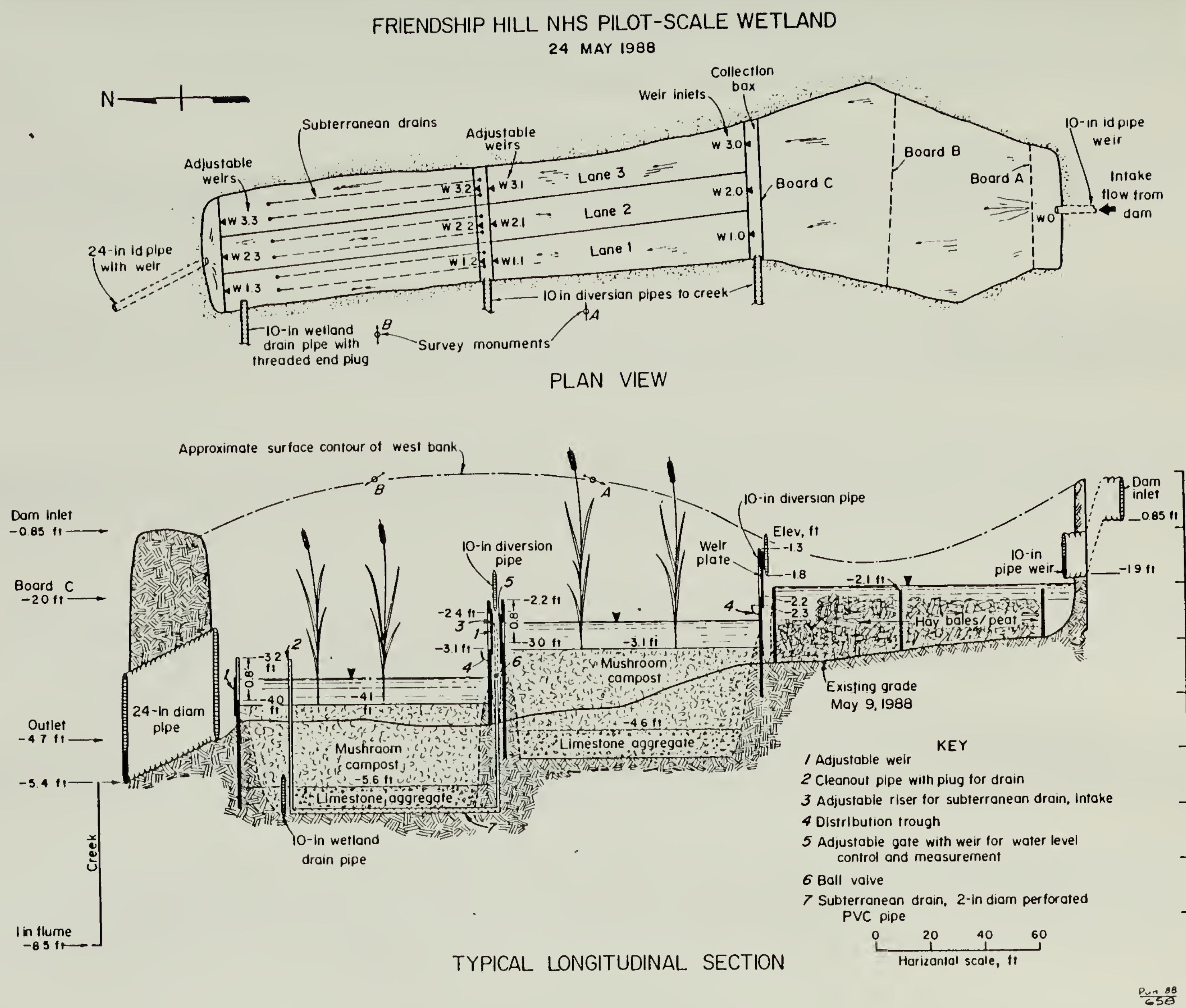
After steady state chemical conditions are established in lanes B and C, select one lane for periodic topical additions of alkalinity ($Ca(OH)_2$).

Water Sampling Schedule

All samples will be analyzed for metals, pH, acidity, and sulfate. Samples will be collected bi-weekly from the common inflow to the first cells (n=1), between the first and second cell in each lane (n=3), and at the outflow of each lane (n=3). The total number of samples collected over a one year period (to begin with the commencement of AMD flow into the Pilot-Scale Wetland) will be 208.

Microbiological Studies

We have recently been in contact with Professor J. Vail, a microbiologist at Frostburg State University in Maryland. Dr. Vail has visited several wetlands constructed to treat AMD in Maryland and Pennsylvania, and is currently culturing iron-oxidizing, manganese-oxidizing, and sulfate-reducing bacteria in his laboratory. He has a new graduate student who will be studying a microbial aspect of the constructed wetland technology. Dr. Vail is very interested in our Friendship Hill plans because it offers an opportunity to relate changes in microbial populations in a newly constructed wetland to measurements of water and substrate chemistry. The park is only an hour drive from the Frostburg State campus. We feel that this is an excellent opportunity for Dr. Vail and his student, as well as NPS and BuMines, because of the added expertise that would be involved in the Friendship Hill research. The student has already recieved a fellowship that covers tuition. If NPS (through the BuMines) would fund a stipend for the student, he would conduct his research at Friendship Hill, as well as visit it three times a week. This added attention would greatly facilitate efforts at Friendship Hill.


FRIENDSHIP HILL NHS PILOT-SCALE WETLAND
24 MAY 1988
N
Subterranean drains
Adjustable weirs
Adjustable weirs
Weir inlets
Collection box
10-in id pipe weir
Intake flow from dam
Board A
Board B
Board C
Lane 3
Lane 2
Lane 1
W 3.3
W 2.3
W 1.3
W 3.2
W 2.2
W 1.2
W 3.1
W 2.1
W 1.1
W 3.0
W 2.0
W 1.0
W 0
24-in id pipe with weir
10-in wetland drain pipe with threaded end plug
Survey monuments
10 in diversion pipes to creek
A
B
PLAN VIEW
Approximate surface contour of west bank
Dam inlet -0.85 ft
Board C -2.0 ft
Outlet -4.7 ft
-5.4 ft
Creek
1 in flume -8.5 ft
24-in diam pipe
10-in wetland drain pipe
10-in diversion pipe
10-in diversion pipe
Elev, ft
-1.3
-1.8
Weir plate
10-in pipe weir
Dam inlet
0.85 ft
-1.9 ft
-2.1 ft
-2.2
-2.3
Hay bales/ peat
-3.2 ft
0.8
-4.0 ft
-4.1 ft
-5.6 ft
-2.4 ft
-3.1 ft
-2.2 ft
0.8
-3.0 ft
-3.1 ft
-4.6 ft
Mushroom compost
Limestone aggregate
Mushroom compost
Limestone aggregate
Existing grade May 9, 1988
KEY
1 Adjustable weir
2 Cleanout pipe with plug for drain
3 Adjustable riser for subterranean drain, Intake
4 Distribution trough
5 Adjustable gate with weir for water level control and measurement
6 Ball valve
7 Subterranean drain, 2-in diam perforated PVC pipe
0 20 40 60
Horizontal scale, ft
ELEVATION BELOW SURVEY STATION A, ft
0 -1 -2 -3 -4 -5 -6 -7 -8
TYPICAL LONGITUDINAL SECTION

Appendix A

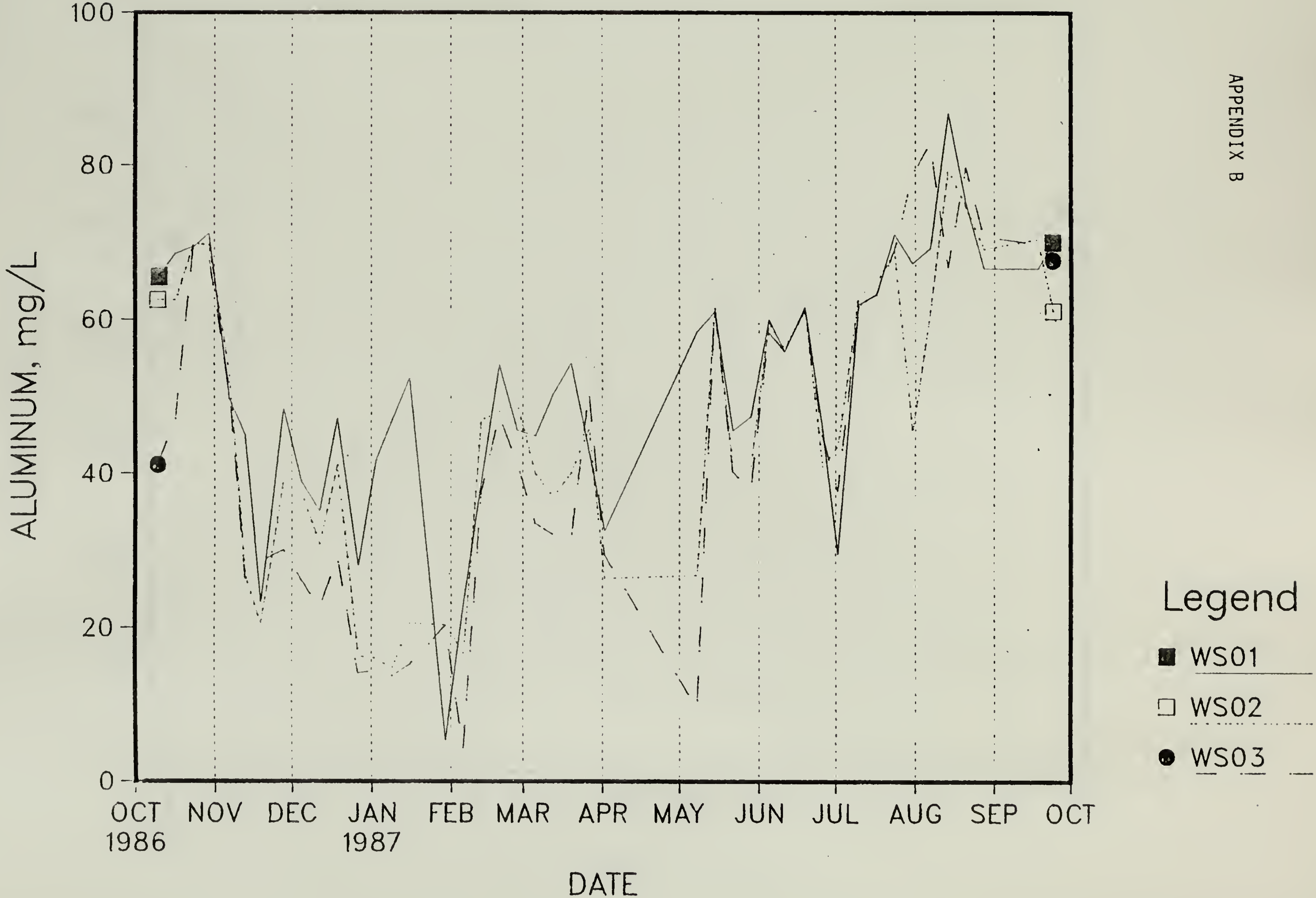
Date	Nt. Acid	Ferrous	Iron	Mn	Al	Sulfate	Temp.
861010	1070.0	7.0	179.0	10.9	65.6	2075.0	-1.0
861010	910.0	68.3	146.0	10.4	62.6	1900.0	-1.0
861010	620.0	121.0	126.0	9.4	41.1	1500.0	-1.0
861017	1100.0	2.5	196.0	11.3	68.6	2137.0	-1.0
861017	1000.0	81.8	170.0	10.7	62.6	2000.0	-1.0
861017	1210.0	139.0	156.0	9.8	46.9	1675.0	-1.0
861024	1180.0	1.3	196.0	11.3	69.5	2300.0	-1.0
861024	1140.0	56.0	191.0	11.4	69.8	2325.0	-1.0
861024	1050.0	89.6	181.0	11.3	69.6	2225.0	-1.0
861030	1220.0	3.4	196.0	11.6	71.2	2212.0	-1.0
861030	1190.0	37.0	191.0	11.6	69.7	2125.0	-1.0
861030	1100.0	76.2	182.0	11.5	68.0	2075.0	-1.0
861107	820.0	2.2	134.0	9.0	49.7	1475.0	-1.0
861107	850.0	85.1	158.0	9.3	52.9	1600.0	-1.0
861107	800.0	34.7	134.0	8.6	50.8	1500.0	-1.0
861113	720.0	5.6	126.4	8.3	45.1	1225.0	-1.0
861113	550.0	9.0	82.1	6.5	26.8	975.0	-1.0
861113	410.0	47.0	71.7	5.2	26.4	725.0	-1.0
861119	380.0	3.8	56.6	4.6	23.4	700.0	-1.0
861119	290.0	2.2	44.5	4.1	20.6	550.0	-1.0
861119	710.0	32.5	64.1	5.2	28.7	775.0	-1.0
861128	810.0	3.6	148.9	8.4	48.5	1425.0	-1.0
861128	590.0	30.2	101.4	6.7	39.3	1025.0	-1.0
861128	460.0	22.4	71.9	5.2	30.1	775.0	-1.0
861205	670.0	3.8	114.2	6.2	38.9	1175.0	-1.0
861205	480.0	77.7	77.7	5.6	37.4	925.0	-1.0
861205	350.0	23.5	52.7	4.1	26.1	625.0	-1.0
861212	660.0	2.3	119.5	5.7	35.2	1125.0	-1.0
861212	570.0	85.1	87.8	4.8	30.9	1000.0	-1.0
861212	330.0	25.8	51.5	3.7	22.6	575.0	-1.0
861219	860.0	3.4	161.3	7.5	47.2	1450.0	-1.0
861219	705.0	57.1	127.1	6.2	41.1	1175.0	-1.0
861219	410.0	21.3	76.8	4.4	29.1	675.0	-1.0
861227	510.0	4.5	85.0	4.1	28.2	900.0	-1.0
861227	250.0	24.6	31.8	2.7	16.4	400.0	-1.0
861227	180.0	12.3	23.9	2.3	14.1	350.0	-1.0
870103	750.0	2.3	135.0	6.3	41.8	1225.0	-1.0
870103	300.0	68.3	69.1	3.1	16.1	500.0	-1.0
870103	210.0	23.5	32.5	2.5	14.5	350.0	-1.0
870109	330.0	95.2	101.5	3.3	14.7	500.0	-1.0
870109	220.0	28.0	40.0	2.5	13.7	400.0	-1.0
870116	887.0	2.3	176.0	8.1	52.5	1630.0	-1.0
870116	419.0	126.0	132.0	4.2	20.6	710.0	-1.0
870116	227.0	20.2	45.8	2.7	15.2	410.0	-1.0
870130	145.0	0.9	8.6	0.9	5.5	270.0	-1.0
870130	374.0	76.2	76.3	3.6	20.4	710.0	-1.0
870130	331.0	63.8	77.0	3.9	20.3	610.0	-1.0
870206	470.0	3.6	75.9	3.6	23.5	825.0	-1.0
870206	285.0	46.1	46.1	2.8	16.8	550.0	-1.0
870206	54.0	1.8	1.8	0.8	4.3	125.0	-1.0
870213	780.0	2.5	151.0	6.8	38.9	1400.0	-1.0
870213	804.0	50.4	104.0	7.2	47.0	1450.0	-1.0

870213	702.0	13.4	122.0	6.2	37.5	1275.0	-1.0
870220	1077.0	2.3	212.0	9.0	54.2	1900.0	-1.0
870220	835.0	44.0	146.0	7.5	47.4	1525.0	-1.0
870227	890.0	2.2	172.0	7.8	45.6	1637.0	-1.0
870227	837.0	123.0	172.0	7.6	49.0	1575.0	-1.0
870227	709.0	28.0	119.0	6.3	41.3	1275.0	-1.0
870306	860.0	2.2	165.0	7.7	44.9	1600.0	-1.0
870306	726.0	121.0	157.0	6.5	40.0	1300.0	-1.0
870306	552.0	17.9	103.0	5.3	33.5	1025.0	-1.0
870313	1025.0	4.5	185.0	8.4	50.4	1812.0	8.0
870313	750.0	179.0	187.0	6.5	37.0	1325.0	6.0
870313	557.0	7.8	99.5	5.2	32.1	1025.0	10.0
870320	1060.0	6.7	198.0	9.3	54.4	1900.0	-1.0
870320	831.0	218.0	227.0	7.3	40.1	1450.0	-1.0
870320	529.0	3.4	87.4	5.4	31.5	1000.0	-1.0
870327	837.0	4.5	159.0	8.0	42.8	1525.0	-1.0
870327	794.0	58.2	113.0	7.7	45.8	1475.0	-1.0
870327	864.0	39.2	137.0	8.3	50.6	1600.0	-1.0
870402	633.0	3.3	123.0	5.8	32.7	1150.0	6.0
870402	519.0	50.4	88.0	4.8	26.5	925.0	6.0
870402	531.0	19.0	88.7	5.2	29.5	1000.0	7.0
870508	1155.0	2.2	223.0	8.5	58.5	1975.0	-1.0
870508	732.0	262.0	262.0	5.5	26.9	1250.0	-1.0
870508	525.0	110.0	174.0	2.8	9.5	750.0	-1.0
870515	1251.0	3.4	244.0	9.1	61.1	2100.0	-1.0
870515	1307.0	15.7	229.0	9.3	61.7	2125.0	-1.0
870515	1230.0	10.1	230.0	9.2	61.6	2125.0	-1.0
870522	954.0	3.4	175.0	7.3	45.6	-1.0	-1.0
870522	879.0	29.1	149.0	6.6	41.1	-1.0	-1.0
870522	830.0	14.6	140.0	6.4	40.2	-1.0	-1.0
870529	1031.0	3.4	184.0	7.8	47.4	-1.0	-1.0
870529	892.0	66.1	151.0	6.7	40.8	-1.0	-1.0
870529	819.0	16.8	135.0	6.2	37.9	-1.0	-1.0
870605	1298.0	2.2	221.0	9.1	60.1	2062.0	17.0
870605	1260.0	20.2	213.0	9.1	59.7	2050.0	21.0
870605	1246.0	14.6	214.0	9.0	58.3	2025.0	22.0
870611	1187.0	3.4	208.0	8.8	55.9	1950.0	17.0
870611	1186.0	22.4	203.0	8.6	56.2	1975.0	18.0
870611	1179.0	10.1	204.0	8.7	56.0	1950.0	18.0
870619	1263.0	3.4	217.0	9.4	61.7	2150.0	-1.0
870619	1331.0	180.0	260.0	9.4	61.4	2150.0	-1.0
870619	1308.0	39.2	229.0	9.4	61.2	2150.0	-1.0
870626	914.0	5.6	161.0	7.9	45.6	1575.0	-1.0
870626	849.0	28.0	125.0	7.1	40.9	1450.0	-1.0
870626	913.0	30.2	142.0	7.6	44.9	1575.0	-1.0
870702	603.0	6.7	101.0	5.6	29.7	1050.0	-1.0
870702	862.0	13.4	131.0	7.1	43.6	1500.0	-1.0
870702	767.0	7.8	119.0	6.4	37.7	1350.0	-1.0
870710	1247.0	5.6	214.0	10.0	62.1	2150.0	-1.0
870710	1236.0	90.7	212.0	10.5	63.1	2125.0	-1.0
870710	1246.0	29.1	215.0	10.1	61.8	2150.0	-1.0
870717	1293.0	4.5	225.0	10.2	63.3	2275.0	24.0
870717	1270.0	7.8	219.0	10.2	64.8	2250.0	24.0
870717	1271.0	19.0	206.0	9.8	63.3	2250.0	30.0
870724	1290.0	4.5	217.0	10.7	71.1	2275.0	-1.0
870724	1360.0	213.0	277.0	10.5	68.9	2325.0	-1.0
870724	1370.0	28.0	210.0	10.8	68.9	2375.0	-1.0
870731	1290.0	3.4	209.0	10.8	67.4	2325.0	23.0
870731	1415.0	199.0	218.0	7.4	45.4	2475.0	23.0
870731	1430.0	4.5	178.0	11.6	78.7	2525.0	26.0

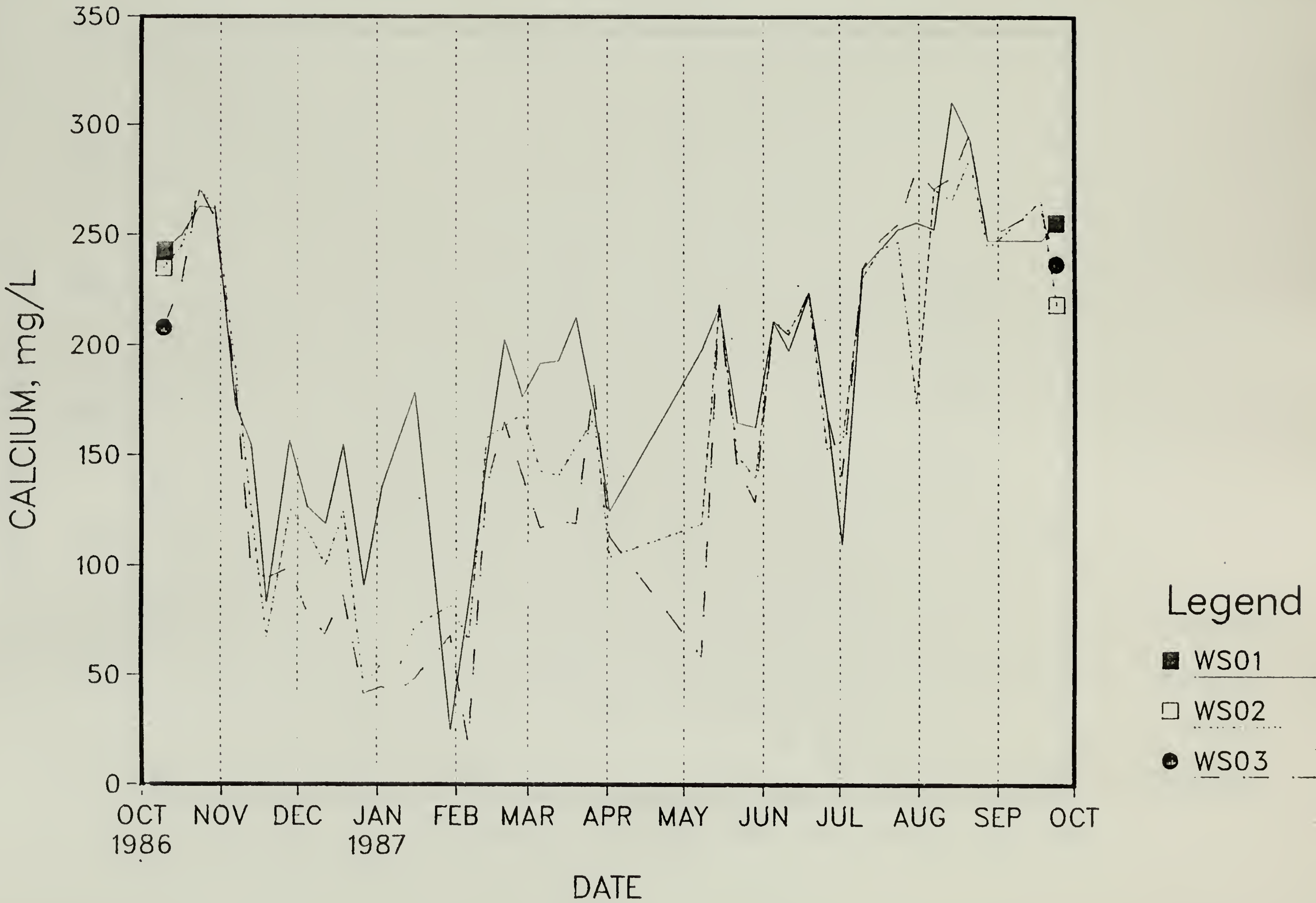
870807	1310.0	3.4	203.0	10.7	69.3	2325.0	23.0
870807	1555.0	219.0	400.0	11.4	61.3	2600.0	23.0
870807	1369.0	3.4	194.0	11.5	82.8	2525.0	23.0
870814	1293.0	3.4	204.0	10.8	86.9	2475.0	20.0
870814	1363.0	272.0	272.0	11.1	79.6	2450.0	22.0
870814	1470.0	210.0	347.0	11.8	66.8	2500.0	22.0
870821	1471.0	3.4	226.0	11.3	75.2	2625.0	18.0
870821	1402.0	185.0	200.0	11.3	74.7	2575.0	20.0
870821	1411.0	22.4	209.0	11.9	79.8	2600.0	21.0
870828	1252.0	2.2	202.0	10.7	66.7	2275.0	-1.0
870828	1164.0	94.1	170.0	11.0	69.2	2175.0	-1.0
870828	1184.0	11.2	173.0	10.9	70.8	2175.0	-1.0
870918	1288.0	3.4	206.0	11.2	66.7	2325.0	20.0
870918	1344.0	114.0	223.0	11.3	70.5	2450.0	24.0
870918	1297.0	5.6	190.0	11.0	69.8	2350.0	26.0
870924	1284.0	3.4	218.0	11.7	70.1	2350.0	16.0
870924	1255.0	109.0	188.0	10.4	61.2	2050.0	19.0
870924	1230.0	2.2	188.0	10.8	67.7	2225.0	23.0

: All concentrations are in mg/L except net acidity which is in mg/L calcium carbonate equivalent.
All water sample temperatures are in degrees Centigrade.
"Sta." is sampling point, "Date" is YYMMDD, "Nt. Acid" is net acidity, "Ferrous" is ferrous iron, and "Iron" is total iron.
"-1" values represent missing data.

APPENDIX B



100
80
60
40
20
0
ALUMINUM, mg/L
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03


CALCIUM, mg/L
350
300
250
200
150
100
50
0
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
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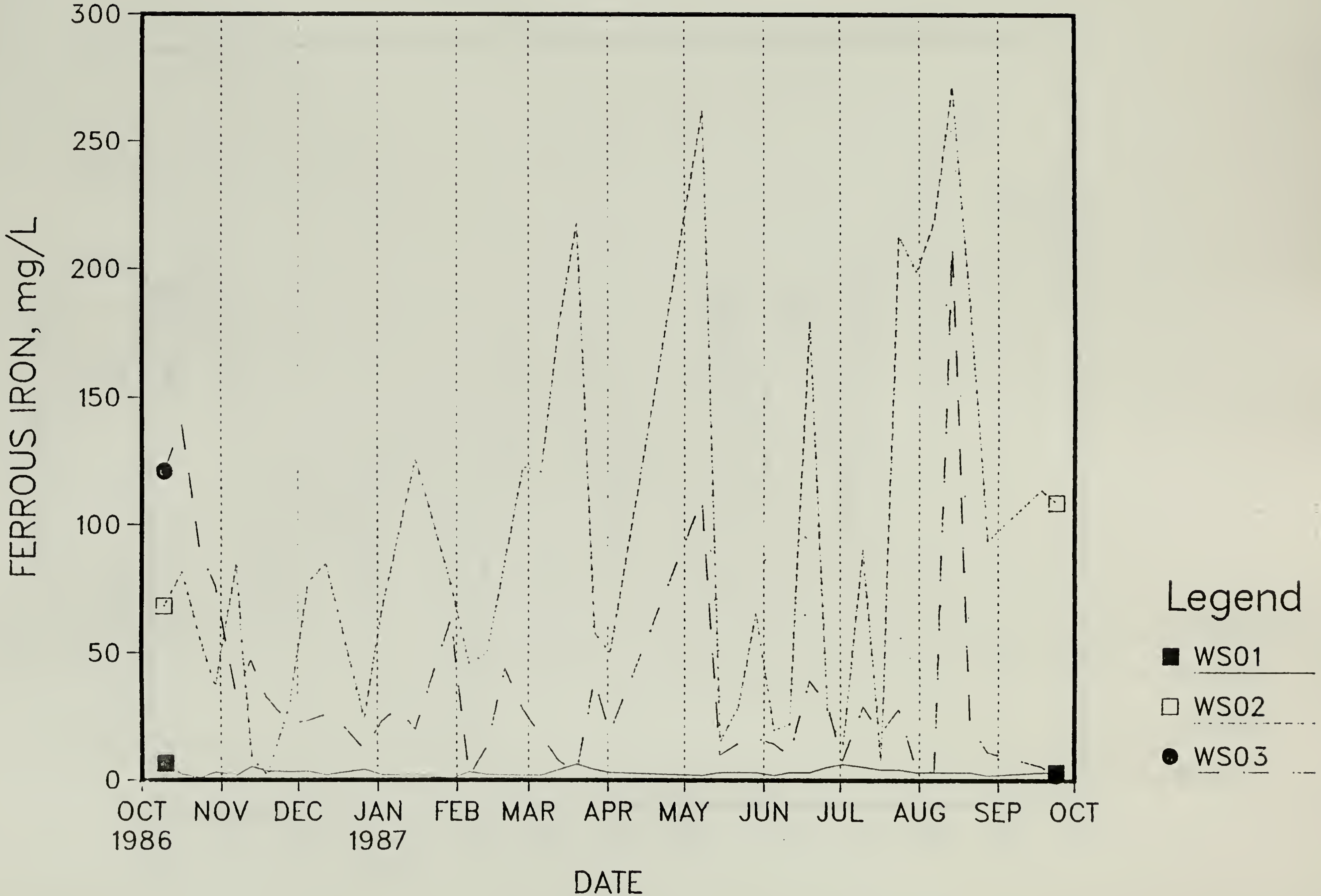
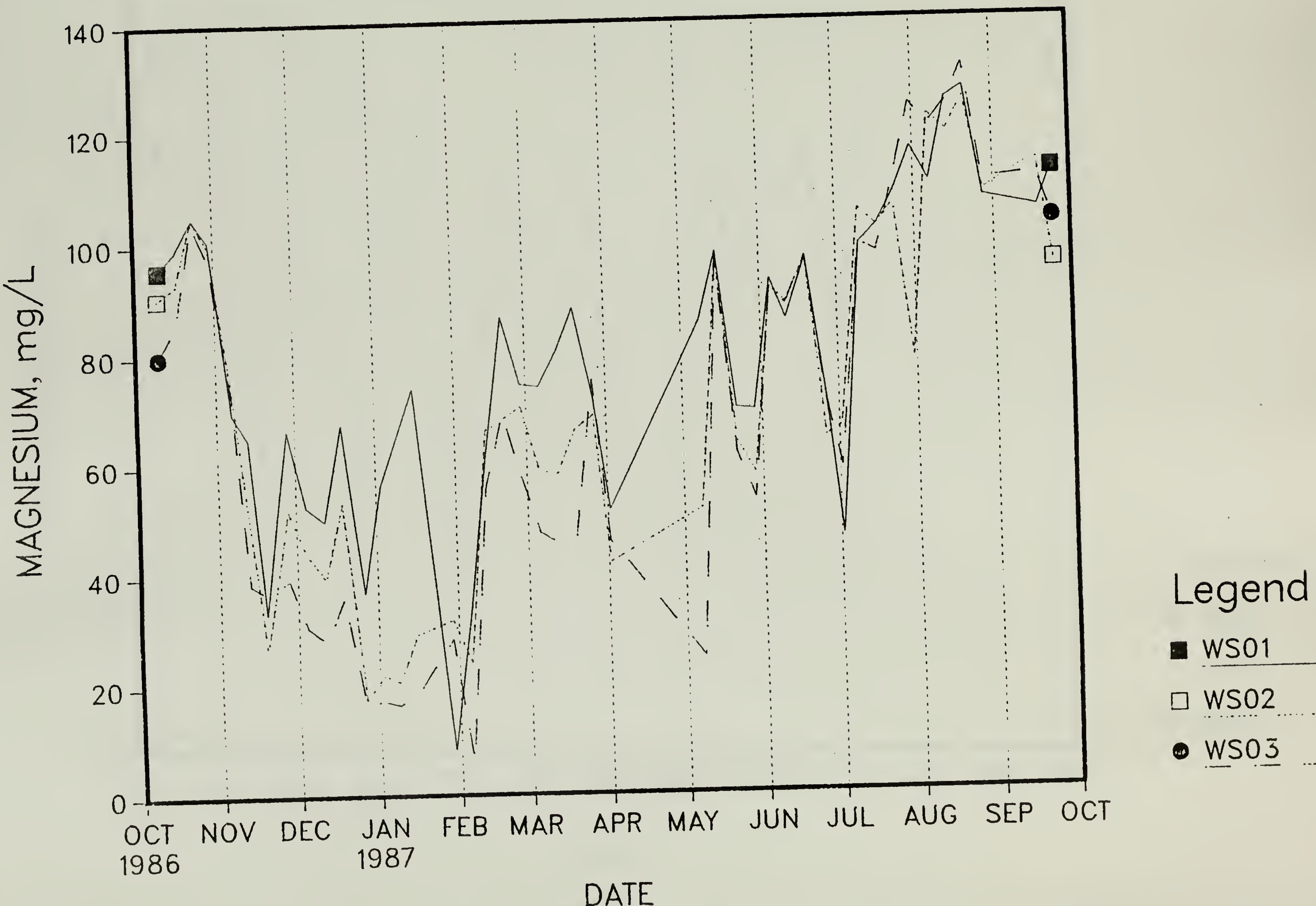
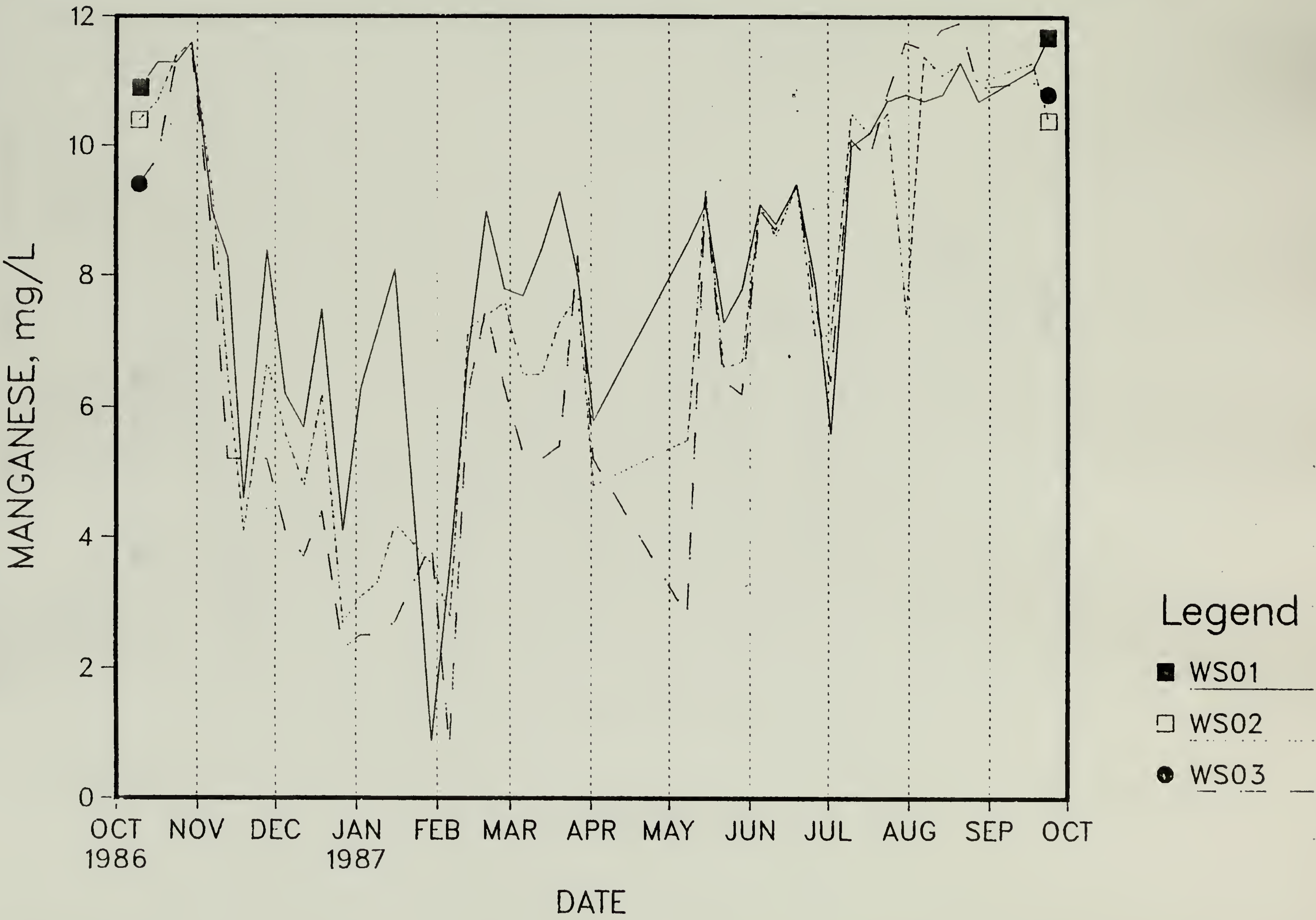
WS01
WS02
WS03

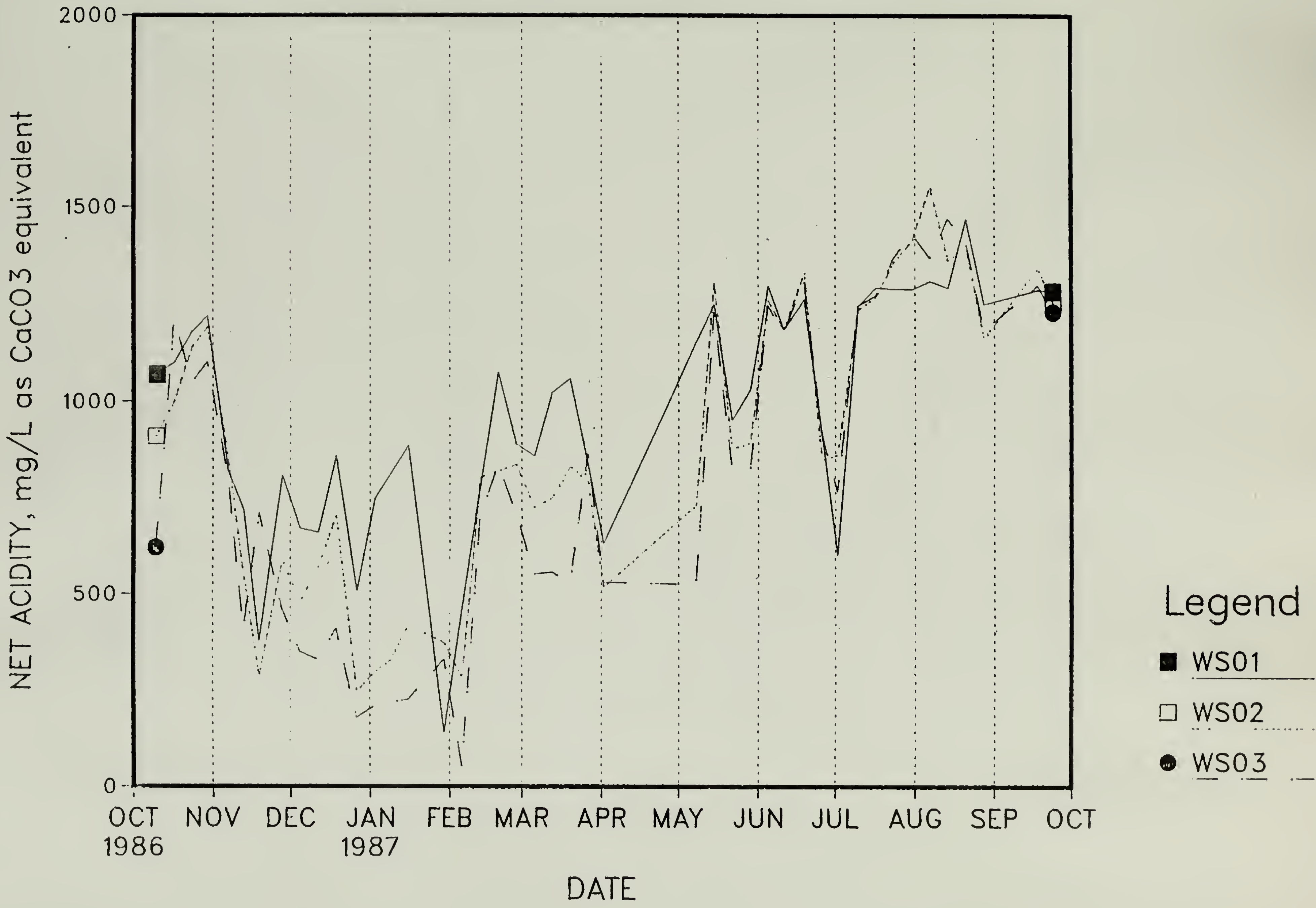


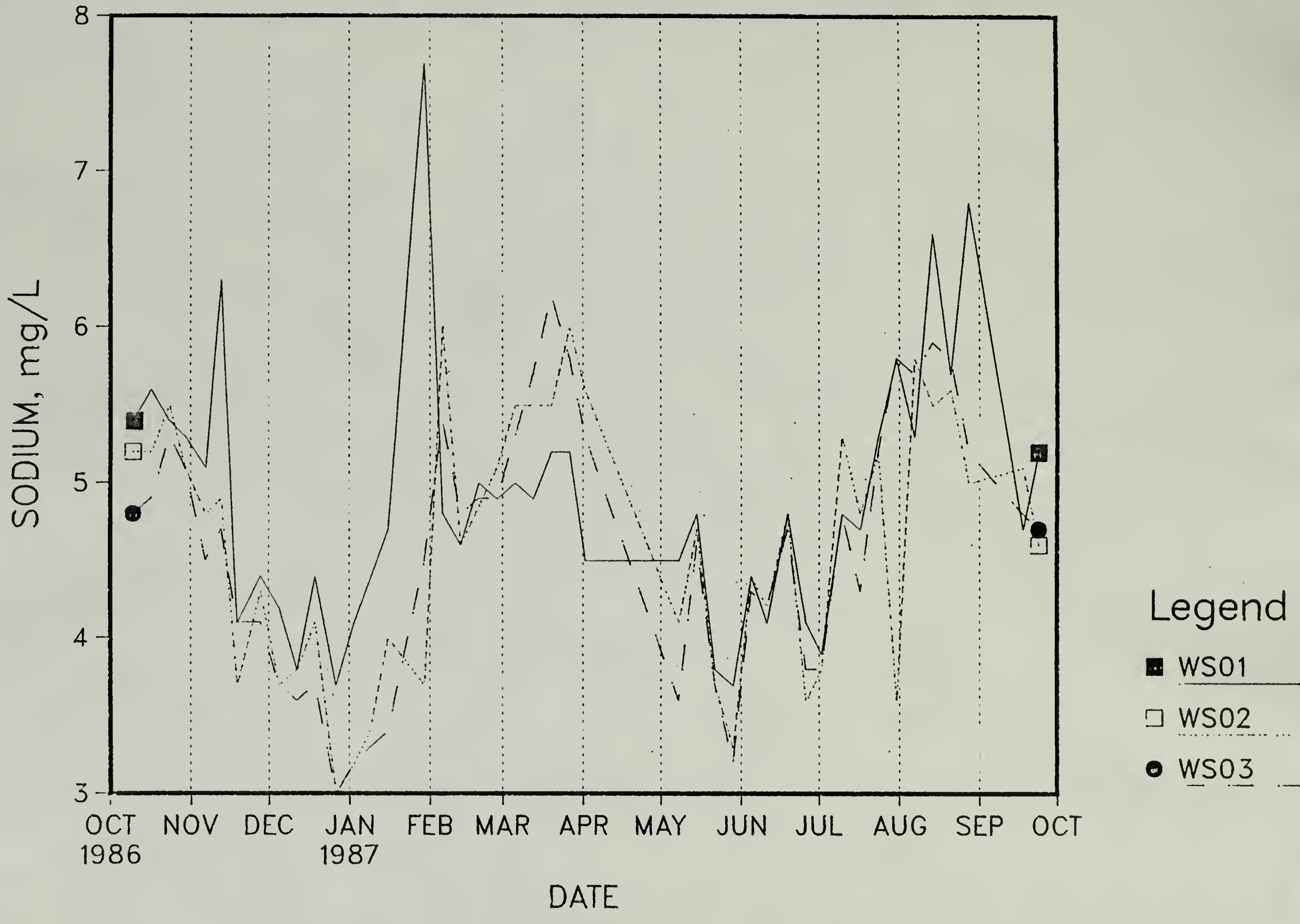
FERROUS IRON, mg/L
300
250
200
150
100
50
0
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03



MAGNESIUM, mg/L
140
120
100
80
60
40
20
0
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03


MANGANESE, mg/L
12
10
8
6
4
2
0
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03


NET ACIDITY, mg/L as CaCO3 equivalent
2000
1500
1000
500
0
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03


SODIUM, mg/L
8
7
6
5
4
3
OCT 1986
NOV
DEC
JAN 1987
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE
Legend
WS01
WS02
WS03